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Mixed convection of Water-Aluminum oxide nanofluid in an inclined lid-driven cavity containing a hot elliptical centric cylinder

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ABSTRACT

The mixed convection in a lid-driven cavity containing a hot elliptical centric cylinder was studied by using of Water-Aluminum oxide (Al_2O_3) nanofluid. The problem was simulated at different Richardson numbers (0.1, 1, 10, 100), different volume fractions (0, 0.1%, and 0.2%), different angles (0°, 15°, and 45°), and temperature difference of 50°C. The obtained results show that by Increase in Richardson number in a constant volume fraction and cavity angle decreases the Nusselt number, because increased Richardson number reduces the nanofluid velocity and increases the shear force. Also, increased in Richardson number reduces the decreasing trend of Nusselt number, because at the Richardson numbers of 0.1–10, the main heat transfer mechanism is forced convection; Also, increase in the temperature difference between the cold walls and the cylinder at a constant Richardson number, volume fraction and cavity angle increase the Nusselt number and heat transfer in such a way that the increasing trend of the Nusselt number depends on volume fraction, fluid velocity, and cavity angle.

1. Introduction

Convection in a lid-driven cavity is relevant to many heat transfer engineering applications such as electronic equipment cooling, food drying, heat exchangers, and nuclear reactors. In recent years, many researchers have studied natural and mixed convection in a cavity under a wide range of thermal conditions in a square enclosure, both experimentally and numerically.

Mansour et al. [1] investigated mixed convection flows in a square lid-driven cavity partially heated from below using nanofluid. They concluded that increasing in solid volume fraction leads to decrease both of activity of the fluid motion and fluid temperature however, it leads to increase the corresponding average Nusselt number.

Talebi et al. [2] executed numerical investigation of laminar mixed convection flows through a copper–Water nanofluid in a square lid-driven cavity. They found that at the fixed Reynolds number, the solid concentration effects on the flow pattern and thermal behavior particularly for a higher Rayleigh number. In addition, they observed that the effect of solid concentration decreases by the increase of Reynolds number.

Shahi et al. [3] executed mixed convection flows through a Copper–Water nanofluid in a square cavity with inlet and outlet ports. Their results indicated that an increase in solid concentration leads to increase in the average Nusselt number at the heat source surface and decrease in the average bulk temperature.

Ghasemi and Aminossadati [4] presented the results of a numerical study on the mixed convection in a lid-driven triangular enclosure filled with a Water–Al_2O_3nanofluid. They concluded that for both upward and downward sliding walls, by adding a larger volume of nanoparticles into the pure Water the rate of change in the heat transfer rate increases.

Mehrizi et al. [5] investigated the effect of suspension of nanoparticles on mixed convection in a square cavity with inlet and outlet ports and hot obstacle in the center of the cavity. Their results showed that by adding the nanoparticles to base fluid and increasing the volume concentration of nanoparticles the heat transfer rate is enhanced at different Richardson numbers and outlet port positions.

Chamkh and Abu-Nada [6] modelled steady laminar mixed convection flow in single and double-lid square cavities filled with a Water–Al_2O_3 nanofluid. They found that significant heat transfer enhancement can be obtained due to the presence of nanoparticles and that this is accentuated by increasing the nanoparticle volume fractions of moderate and large Richardson numbers using both

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nanofluid models for both single- and double-lid cavity configurations.

Garoosi et al. [7] investigated natural convection inside a square cavity filled with nanofluids with several pairs of heaters and coolers (HACs) inside. They indicated that the heat transfer rate at all Rayleigh numbers can be enhanced more efficiently by increasing number of HACs than increasing the HAC size.

Hemmat et al. [8] analyzed combined convection within a lid-driven square cavity subjected to variable properties of nanofluid having a hot obstacle. Their results showed that the average Nusselt number decreases with increasing temperature of nanofluid for the whole range of the Richardson numbers. Also heat transfer augments as the height of the heat obstacle on the bottom wall increases.

Hassanzadeh Afrouzi and Farhadi [9] investigated mixed convection flow in a square lid-driven cavity utilizing nanofluid in presence of cubic obstacle. Their results indicated that the averaged Nusselt number increases by augmentation of the solid volume fraction. Also, The Richardson number had more effect on the Nusselt number when the obstacle was located at the bottom section of enclosure

Chatterjee et al. [10] investigated the mixed convective transport of Cu-H_2O nanofluid in a differentially heated and lid-driven square enclosure in the presence of a rotating circular cylinder. They observed that the heat transfer greatly depends on the rotational speed of the cylinder, mixed convective strength and the nanoparticle concentration.

Hemmat Esfe et al. [11] investigated mixed-convection fluid flow and heat transfer in a square cavity filled with Al_2O_3–Water nanofluid. Their results elucidated irregular changes of a mean Nusselt number of different Richardson numbers versus variation of inclination angles in any case.

Garoosi et al. [12] carried out a numerical study concerning natural and mixed convection heat transfer of nanofluid in a two dimensional square cavity with several pairs of heat source-sinks. Their simulation results indicated that there is an optimal volume fraction of the nanoparticles for each Rayleigh number and Richardson number at which the maximum heat transfer rate occurs.

Selimefendigil and Öztop [13] investigated mixed convection in a cavity with volumetric heat generation and filled with nanofluid having an inner rotating cylinder and two flexible side walls. They observed that the local and averaged heat transfer enhances as the external Rayleigh number, nanoparticle volume fraction and absolute value of the angular rotational velocity of the cylinder increase and as the internal Rayleigh number decreases.

Elimefendigil and Öztop [14] investigated natural convection in a nano-fluid filled cavity having different shaped obstacles (circular, square and diamond) installed under the influence of a uniform magnetic field and uniform heat generation. They concluded that the presence of the obstacles deteriorates the heat transfer process and this is more pronounced with higher values of Re.

Hemmat Esfe et al. [15] studied mixed convection fluid flow and heat transfer of an Al_2O_3–Water nanofluid with the thermal conductivity and effective viscosity dependent on temperature and nanoparticle concentration inside a lid-driven cavity having a hot rectangular obstacle. Their results indicated that addition of Al_2O_3 nanoparticles produces a remarkable enhancement of heat transfer with respect to that of the pure fluid.

Darzi et al. [16] studied laminar mixed convection heat transfer characteristics within an obstructed enclosure. Their Results indicated that heat transfer decreases with a rise of the Richardson number for all considered arrays of cylinders.

Garoosi and Hoseininejad [17] studied natural and mixed convection in an adiabatic enclosure containing several pairs of hot and cold cylinders. They found that by changing the location of the heat source/sink from bottom–top to top–bottom configuration the heat transfer rate decreases significantly.

Doustdar and Yekani [18] studied the mixed convection of aluminum oxide-Water Nano fluid inside a square cavity containing hot quadrilaterals obstacles on its bottom wall. Their results showed that the increase of Rayleigh number as well as the volume fraction of nanoparticles will increase the heat transfer inside the cavity.

Hemmat Esfe et al. [19] evaluated the mixed convection flow and heat transfer of functionalized DWCNT/Water nanofluids with variable properties in a cavity having hot baffles. Their results showed that with an increasing nanoparticles volume fraction and the distance between the left hot baffles of nanoparticles average Nusselt number enhances for all considered Richardson numbers and cavity inclination angles.

Rashad et al. [20] performed a numerical simulation of inclined magneto-hydrodynamic mixed convection and partial slip in a square lid-driven cavity filled with a Darcian nanofluid saturated porous medium. Comparisons with previous published works were presented and found to be in excellent agreement.

Wongwises et al. [21] investigated the heat transfer and fluid flow within a lid-driven, inclined, square cavity containing three circular heat sources. According to their results, as the Richardson number increases, the average Nusselt number decreases. Furthermore, at a constant solid volume fraction as the inclination angle increases the average Nusselt number enhances.

Hence, we observed that the results indicate that, adding nanoparticles to the base fluid causes an impressive enhancement of heat transfer coefficient in the nanofluid and investigating and estimating the nanofluid behaviors in the novel surfaces of heat transfer have a widespread progress among the researchers [22–66].

Mixed convection of Water-Aluminum Oxide nanofluid in an inclined lid-driven cavity and elliptical centric cylinder is an objective of the present investigation. In order to examine this objective, Aluminum oxide at different volume fractions (0, 0.1% and 0.2%) at different Richardson numbers (0.1, 1, 10, 100), different angles (0°, 15° and 45°), and temperature difference of 50 °C were investigated. The effect of Richardson number, volume fraction and geometrical parameters on fluid flow and heat transfer were examined.

2. Numerical model

2.1. Physical model

In this research, mixed convection heat transfer in an inclined lid-driven cavity containing a hot elliptical centric cylinder at a constant temperature (T_h) is investigated. Top, bottom, front and rear walls are insulated and the top wall is moving in the positive direction. The schematic diagram of the geometry and the computational domain is shown in Fig. 1. The length, height and the width of the cavity are given by L. The right and left side walls are maintained at a constant temperature (Tc). The nanofluid is assumed incompressible and the flow is conceived as laminar and two-dimensional. It is idealized that Water and nanoparticles are in thermal equilibrium and no slip occurs between the two media.

2.2. The governing equations

The governing equations for laminar, steady-state lid-driven mixed convection in a 3-D enclosure filled with a nanofluid are given as:

Continuity equation [9,15,29–34]:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$